

EIC Detector R&D

Progress Report FY18

Project ID: eRD3

Project Name: Design and assembly of fast and lightweight forward tracking prototype systems for an EIC

Period Reported: July 2017 – December 2017 (Status)

Project Leaders:

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Introduction

This report concentrates on a dedicated tracking system based on micro-pattern detectors, which focuses on the design and development of fast and lightweight detectors, ideally suited for a future EIC experiment. The science case and basic detector specifications have been documented in a White paper report [1]. The micro-pattern tracking detector system consists of:

- Barrel tracking system based on MicroMegas (MM) detectors manufactured as six cylindrical shell elements.
- Rear / Forward tracking system based on triple-GEM detectors manufactured as planar segments of three layers in the rear and forward directions.

An alternative layout for the MM barrel tracking system consists of a TPC together with one inner and outer fast radial MM layer to aid the actual TPC track reconstruction. This option has not been worked out in detail yet.

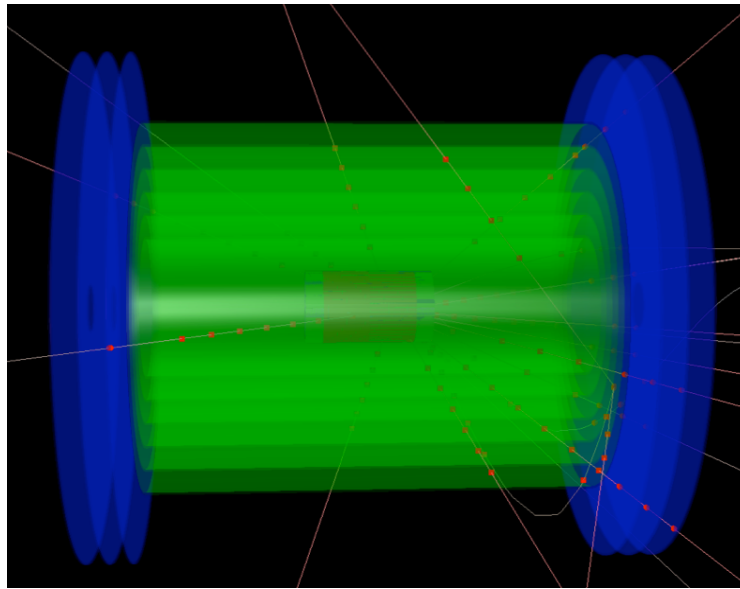


Figure 1: *GEANT simulation of barrel (green) and rear / forward (blue) tracking systems for an EIC detector.*

Figure 1 shows a 3D view of a GEANT simulation for a barrel and rear / forward tracking system which has been initiated by the R&D program documented in this report. The R&D effort focuses on the following areas:

- Design and assembly of large cylindrical MicroMegas detector elements and planar triple-GEM detectors,
- Test and characterization of MicroMegas and triple-GEM prototype detectors,

- Design and test of a new chip readout system employing the CLAS12 DREAM-chip development, ideally suited for micro-pattern detectors,
- Utilization of light-weight materials,
- Development and commercial fabrication of various critical detector elements and
- European/US collaborative effort on EIC detector development (CEA Saclay and Temple University).

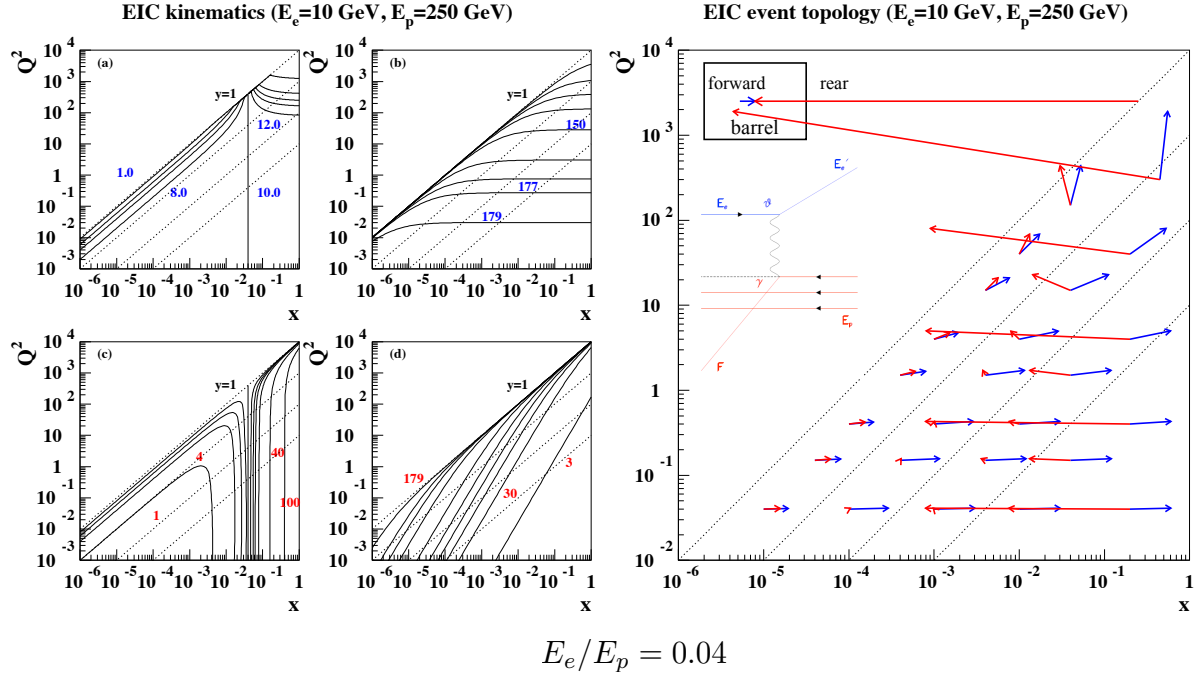


Figure 2: EIC kinematics shown as isolines (left) and event topology (right) in the Q^2 - x plane for 10 GeV (electron) on 250 GeV (proton) beams. Electron variables are shown in blue whereas proton / current-jet quantities are shown in red. The upper left box indicates the initial state configuration of 10 GeV (blue) on 250 GeV (red). The magnitude of each arrow is a reflection of the energy whereas the direction is the polar angle direction

The basic kinematic requirements of ep physics will be summarized below. Using basic energy and momentum conservation in ep scattering, the ep event kinematics as shown in Figure 2 in terms of x (or y) and Q^2 can be characterized by the scattered electron in terms of its energy and polar angle or in terms of the struck quark giving rise to a current jet characterized by its respective energy and polar angle. All polar angles are measured with respect to the initial-state proton direction.

At low and moderate Q^2 and low x , both the current jet and the scattered electron have very low energy and are predominantly found in the rear direction. For fixed low and moderate Q^2 and increasing x values, the current jet is moving away from the rear direction into the barrel and eventually at high x in the forward direction. The rear direction is characterized by extremely small

electron energies which is even more pronounced at smaller center-of-mass energies which is generally required for F_L -type measurements. Low dead material ($\leq 1\% X_0$), a precision energy measurement ($\leq 10\%/\sqrt{E}$) and precise hit localization ($\leq 1\text{ mm}$) along with precision energy calibration ($\leq 0.5\%$) and alignment ($\leq 1\text{ mm}$) at a rear calorimeter system are critical. The requirements in the forward direction are less stringent due to the larger energies in the final state. This has been shown by both the H1 and ZEUS experiments at HERA which will become even more challenging at an EIC facility due to the smaller beam energies. All of those items turned out to be challenging aspects if not taken care of properly [2]. A triple-GEM forward and rear tracking system provides the needed precision hit localization directly in front of a rear and forward calorimeter system and aids in the understanding of pre-showering and dead material mapping. In the rear direction, a precision hit determination for scattered electrons is indispensable for precise Q^2 reconstruction and critical for probing ep collisions as a function of large to low Q^2 . In the forward direction precise hit localization is critical for a) particle track/calorimeter mapping and b) required to enable hit points in front and behind the forward RICH detector system as featured in the JLEIC detector design¹.

This report provides an overview of various R&D activities in Q4 FY17/ Q1 FY18. Following the last meeting of the EIC R&D committee in July 2017, the allocation of funds of \$41,800 for FY18 are in the process of being transferred to Temple University. Our new postdoc, Dr. Amilkar Quintero, started on June 01, 2016. He completed his Ph.D. thesis work with the STAR experiment at RHIC on the STAR Heavy Flavor Tracker at Kent State University. He has a lot of experience with tracking software and has prior experience with micro-pattern detectors at CERN while completing a Master's Degree at Florida Institute of Technology with Professor Marcus Hohlmann, our collaborator of the EIC eRD6 program. The bulk of the EIC R&D program was so far carried out by Dr. Matt Posik besides his physics analysis efforts at the STAR experiment. His appointment at Temple University is now shared between the College of Science and Technology at Temple University and the EIC R&D sub-contract. Dr. Amilkar Quintero will be trained by Dr. Matt Posik and will share his commitment between the EIC R&D program (~20%) and the physics analysis program of high-energy polarized p+p physics (~80%) with Professor Bernd Surrow at RHIC covered by his DOE Nuclear Physics base grant. The College of Science and Technology is strongly supporting the R&D program with both manpower and equipment support. Mr. James Wilhelmi, a mechanical engineer, provides dedicated support for Nuclear Physics research activities at Temple University. We do consider this and the local new machine shop an outstanding resource for our detector development work.

It should be emphasized that our R&D program is a dedicated development, in particular to commercial development, of various elements for a future EIC tracking detector system. The generic R&D program is on track to be completed in 2019. It is then planned to enter a phase of targeted EIC detector design work focusing on specific prototyping assembly and testing activities in close collaboration with the Florida Institute of Technology (FIT) and the University of Virginia (UVa) in preparation of a Technical Design Report required in part for the DOE Critical

¹ https://eic.jlab.org/wiki/index.php/Main_Page

Decision process after the completion of the ongoing National Academy of Sciences review of the EIC physics program.

Over the last reporting period we have promoted our EIC R&D research efforts with a presentation based on the status of our R&D program at the Micro-Pattern Gas Detector (MPGD) 2017 conference this past May.

The lack of funding for the MM part concerning the 2D development is a serious concern. It should be emphasized that the MM part is the only dedicated MM tracking system presented so far and currently provides the only alternative to a full TPC option.

The International Advisory Committee of the MPGD conference series selected Temple University to host the MPGD 2017² conference, together with a full-day RD51 collaboration meeting. This conference took place on May 22-26, 2017 at Temple University with about 100 participants from Asia, Europe and North and South America. We do consider the selection by the International Advisory Committee to host the International MPGD conference as a strong recognition of the EIC R&D program [3, 4, 5, 6, 7] on an international level. It was stated during various overview presentations that the US MPGD community is centered around the EIC R&D program.

Forward Triple-GEM R&D Program: Progress Report

What was planned for this period?

Over the time period of July - December 2017, we had planned to carry out research in several areas:

1. Finish the upgrade of our CCD GEM scanner, which quantifies GEM foil quality based on geometrical properties, to accommodate GEM foils up to 1 meter long.
2. Construction of several 40 cm x 40cm triple-GEM tracking detectors using commercial single-mask GEM foils, HV foils, and readout foils all produced by Tech-Etch. These detectors will allow us to study and compare the GEM quality of a commercial foil to that of the well established CERN foils. These prototype triple-GEM detectors also allow us to investigate replacing the standard G10 spacer grids, which sit between GEM foil layers in a triple-GEM detector to keep the layers from sagging and touching, with thin Kapton spacer rings. The Kapton spacer rings present the potential to reduce both cost and dead material compared to the more conventional spacer grids.

² MPGD2017 WWW-page: <https://phys.cst.temple.edu/mpgd2017/>

3. Design of a radiation enclosure to operate a 50-keV X-ray tube, which is needed for triple-GEM detector gain and efficiency measurements.

What was achieved?

We have made good progress on the goals that we had planned for the time period of July - December 2017:

1. CCD GEM Scanner

A CCD GEM scanner allows one to image and optically analyze the geometrical properties of GEM foils, such as the GEM hole pitch, inner hole and outer hole diameters. These properties can be used, in addition to electrical leakage current tests, to determine the foils overall quality. This is not only important when building detectors, but was also found to be a vital component in developing the process used by Tech-Etch to commercialize GEM foils. With the forward tracking designs of a future EIC ranging from about 40 cm up to about 1 m long, it is critical that we update our GEM foil CCD scanner if we want to be able to analyze any potential EIC type foils.

Our previous setup was not suitable to scan foils above 15 cm x 10 cm. To allow the scanning of larger area GEM foils (up to 100 cm x 60 cm) we designed a CCD scanner around two larger linear stages of 100 cm and 80 cm travel range. The large area CCD GEM scanner was built on a new Newport optical table (6 ft x 4 ft), which is located in Temple University's MPGD clean room facility. The optical table is part of a generous gift provided to the College of Science and Technology at Temple University. The machining and assembly of the scanner has now been completed by our mechanical engineer Mr. James Wilhelmi. In addition to upgrading the scanning area of the CCD scanner, the CCD camera used to capture images of the GEM foil was also upgraded. We have now ordered, installed, and verified the functionality of the DMK 23F445 model camera ordered from 'The Imaging Source'. This camera upgrade not only improves the pixel size and image resolution, but also captures images with a larger field of view. This upgrade has now been completed and the initial software has been calibrated and commissioned.

We have now completed optical scans of all twelve Tech-Etch single mask foils that Temple University had received. These images are now being processed with image analysis software to extract foil hole geometries. In addition to optically scanning the Tech-Etch foils, we have also been working with both UVa and FIT. Recently we scanned two 10 cm x 10 cm chromium GEM foils for UVa, and FIT was able to send us a "bad" prototype EIC GEM foil, which was designed by the eRD3 and eRD6 groups, to measure its' geometrical properties.

Chromium GEM Scans

While scanning the chromium GEMs, two issues were discovered. First, with the copper layer removed from the GEM foil our CCD setup was unable to adequately illuminate the foil. Even when looking at a chromium foil that had only one copper side removed we were unable to get a

well lit image. We tried to work around this issue by increasing the CCD cameras gain, however this led to a significant increase of the noise in the images. The second issue that was encountered was when trying to scan the chromium outer hole diameters, residual copper or other material remaining on the foil caused a high reflectivity with the camera gain increased. Figure 3 shows a CCD image of the chromium GEM foil (a) compared to a conventional GEM foil (b). These reflections and camera noise prevented us from accurately measuring the foil's outer hole diameters.

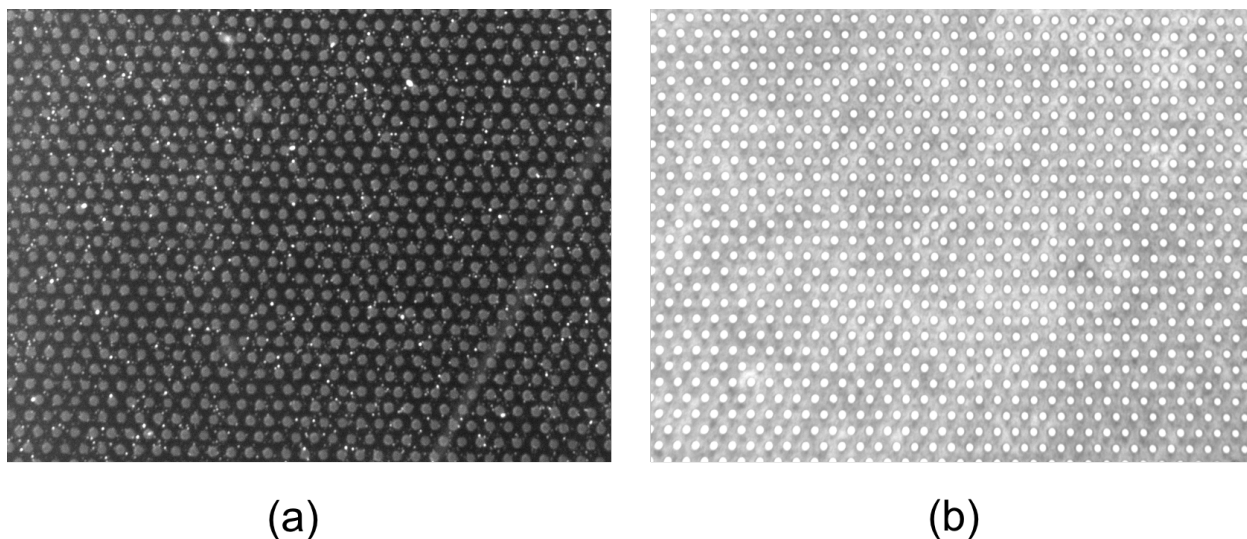


Figure 3: *CCD images of outer hole diameters for a chromium (a) and traditional copper clad (b) GEM foil.*

Although we were unable to measure the outer hole diameters, none of the above issues applied to the inner hole diameter measurements. Figure 4 shows the pitch (a) and inner hole diameter (b) distributions for one of the chromium GEM foils. The optical scans revealed a double pitch structure, which was seen in both chromium foils that were scanned, while the mean inner hole diameter was found to be around 50 μm , with narrow spread of about 1.5 μm .

Common EIC Prototype Foil

FIT had sent use a damaged EIC prototype foil, which was collectively designed by eRD3 and eRD6 groups. During the previous scanning of this foil, the camera was found to defocus at the edges of the 1 m long GEM foil. This issue was caused by the sagging of the plexiglass bed that the GEM foil was resting on. We have now replaced that bed with a thicker glass bed to eliminate the sagging. The pitch (a) and inner hole diameter (b) distributions can be seen in figure 5. Similar to what was seen in the chromium GEM scans, the pitch distribution shows a second smaller peak/shoulder. Figure 6 shows the inner hole diameter deviations from the mean across the area of the GEM foil.

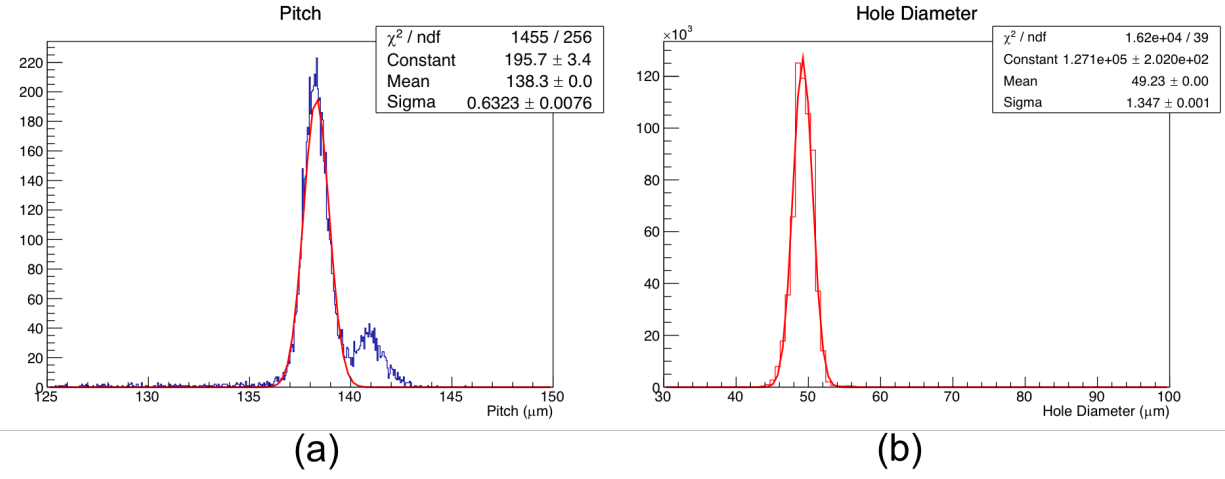


Figure 4: Pitch (a) and inner hole diameter (b) distributions for a chromium GEM foil.

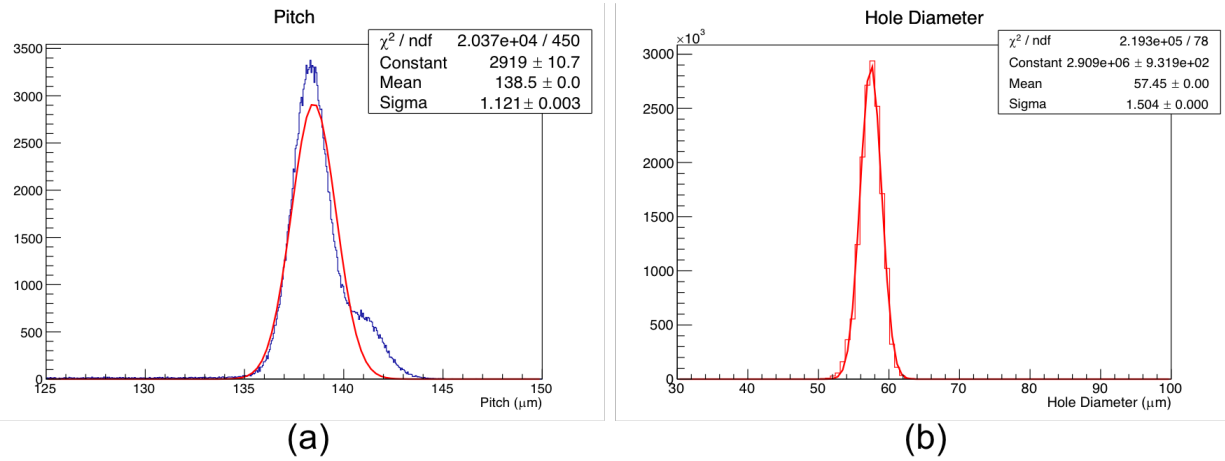


Figure 5: Pitch (a) and inner hole diameter (b) distributions for common design EIC GEM foil.

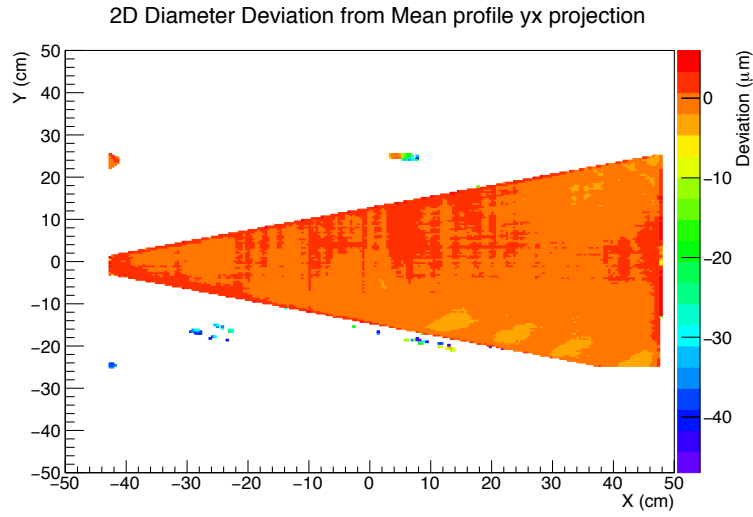


Figure 6: Inner hole diameter deviation from the mean as a function of area for the common design EIC GEM foil.

2. 40 cm x 40 cm Prototype triple-GEM Detectors

In our previous report we were unable to begin the assembly of the triple-GEM detectors because we were still awaiting the completion of our large GEM storage boxes, in which we would store bare foils and partially assembled detector components under N₂ flow. These boxes have now been completed and are capable of holding 1m long GEM foils. Figure 7 shows the two large GEM storage boxes under N₂ flow in the Temple MPGD clean room facility.

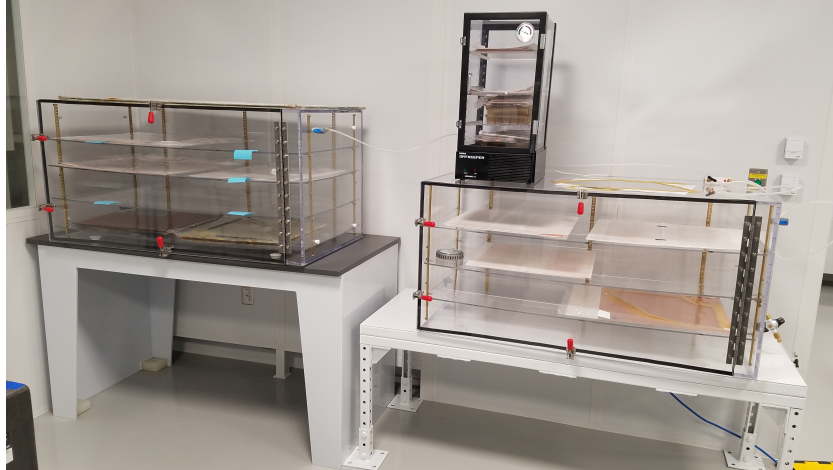


Figure 7: Two MPGD clean room large GEM storage boxes.

With the completion of the GEM storage boxes, we could then begin the triple-GEM assembly process. The triple-GEM detectors are based on the STAR FGT [8]. The FGT design was chosen to save both money and time. Temple University already has all of the tooling specific to the FGT design that is needed to build a triple-GEM detector. This includes a nitrogen enclosure for

leakage current testing, a stretching jig for gluing the foils and frames, a design for the HV foil, frame design, readout board design, and soldering station. Those items are all located inside our MPGD clean room facility.

As of this report we have assembled two triple-GEM detectors. Both use Tech-Etch produced single mask foils, HV foils, and readout foils. The only difference between the two detectors is that one was built using the Kapton spacer rings, while the other used the more conventional G10 spacer grids. Figure 8 shows the layer of Kapton spacer rings (a) and G10 spacer grids (c) being inserted to separate two GEM foils. Figure 8b and 8d, show the completed assembly of the two detectors using Kapton rings and spacer grids, respectively, to separate the foil layers.

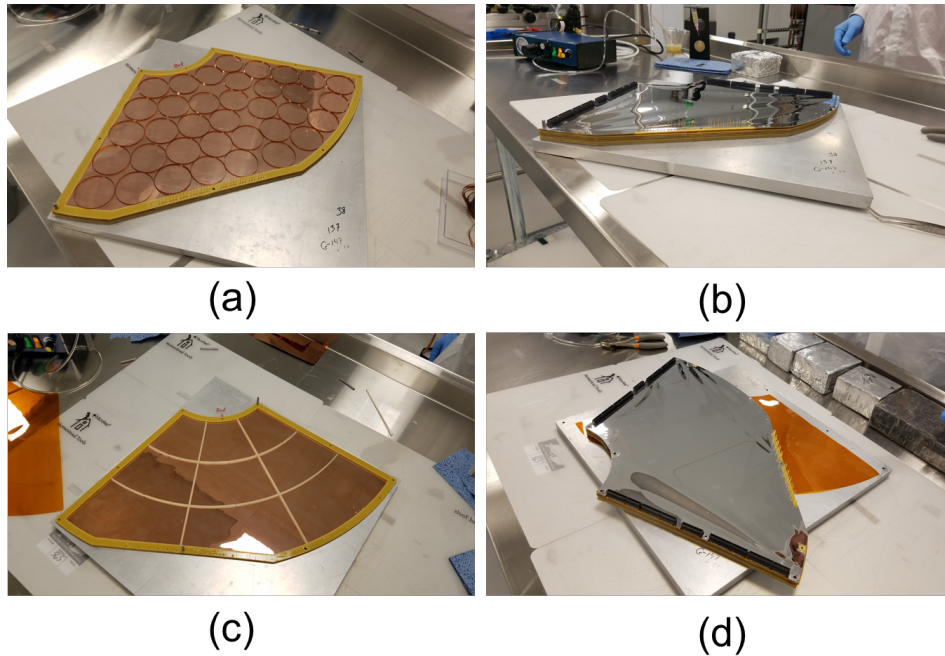


Figure 8: Two triple-GEM detectors using Tech-Etch foils. (a) shows the application of the Kapton spacer rings, (b) completed triple-GEM detector using the Kapton spacer rings, (c) shows the application of the G10 spacer grids, and (d) shows the completed triple-GEM detector using the G10 spacer grids.

Initial electrical tests of the triple-GEM detector built with the Kapton spacer rings looked good. This included leakage current measurements of each of the nine sectors for all three GEM foil layers. At 500 V all sectors showed good leakage currents near or below 1 nA under N₂ flow. The triple-GEM detector was then connected to the STAR DAQ setup in Temple University's detector lab, where a voltage of about 3 kV was applied to the triple-GEM detector and its current was monitored for about 1.5 days to see if there was any noticeable charge-up effects. After 1.5 days, no evidence of charging-up was seen. We also compared the Kapton ring GEM detector to several STAR FGT triple-GEM detectors (those used in the actual STAR FGT), where we no-

ticed that the GEM detector built with the Kapton rings showed a current of about 500 uA, roughly a factor of 1.5 times higher than the STAR FGT quadrants.

As of this report we have just finished the assembly of the triple-GEM detector built with the spacer grids and are currently in the process of ensuring that there are no gas leaks. Once the detector is gas tight and has been flushed with N₂, we plan on repeating the same electrical tests that were done with the triple-GEM detector built with the Kapton rings. We hope testing this detector will allow us to determine if the Kapton rings could be responsible for the larger detector current.

After the initial electrical tests of the triple-GEM detector built with the spacer grids, we will begin our cosmic ray testing of the detectors to quantify their efficiency. In the mean time we have also sent several Kapton rings to the BNL lab where they are already equipped to do an x-ray scan of the Kapton rings to determine the level of electric field distortion that is caused by the rings. We are eagerly awaiting those results.

What was not achieved, why not, and what will be done to correct?

We have not yet begun the cosmic ray testing of the triple-GEM detectors, however with two chambers now assembled this will become our immediate focus. Once some initial results start to come in from the cosmic data and the Kapton ring x-ray scan we will consider our options for building a third prototype triple-GEM detector.

The design of the radiation enclosure is in progress.

What is planned for the coming months and beyond? How, if at all, is this planning different from the original plan?

In the upcoming months our efforts will be focused on finishing out our already proposed R&D. This includes cosmic ray and ⁵⁵Fe testing of the prototype triple-GEM detectors built using Tech-Etch GEM, HV, and readout foils. As well as comparing the results of the two prototype detectors, one built using Kapton space rings and the other using G10 spacer grids. Additionally, we also plan to complete the x-ray enclosure, needed to operate our high rate x-ray gun.

Barrel MicroMegas R&D Program

Past

What was planned for this period?

In FY16 / FY17, we had planned to carry out R&D efforts on the DREAM chip application to GEM detectors and 2D curved resistive MicroMegas prototype detectors: this technology has the clear advantage of minimizing the amount of material with respect to two 1D detectors.

What was achieved?

In 2016, the Saclay group was able to successfully design, build and test a transition card to connect a FGT quarter section triple-GEM detector to their current DREAM front-end-electronics. To connect the FGT to the DREAM electronics, a passive transition card was built to connect the 2 “super-connectors” of one FGT quarter section to the MEC8 connectors used with the DREAM front end electronics. This FGT-DREAM card replaces the FGT-APV cards and allows the detector to readout using the DREAM chips rather than the APV chips. In addition to the GEM readout electronics work, the Saclay group has also continued further cosmic ray testing of their 1D MicroMegas barrel detector.

What was not achieved, why not, and what will be done to correct?

The lack of R&D funding delayed the process of the 2D Micro-meags R&D work.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

2D MicroMegas Detector

With the success of the two 1D MicroMegas detectors presented in the last progress report, we would like to continue the development of the cylindrical MicroMegas detector by building a large 2D curved resistive MicroMegas detector.

What are the critical issues?

None.

Manpower

Postdoctoral support of 50% was the basis of the FY2017 sub-award. This amount allowed to support both Dr. Matt Posik and Dr. Amilkar Quintero. Dr. Matt Posik worked at the level of 50% of his time on the EIC R&D program whereas Dr. Amilkar Quintero worked at the level of 20% on the EIC R&D program.

External Funding

Temple University and Saclay did not receive any other grant funding in support of the actual R&D program discussed here. However, it should be emphasized that Temple University provided substantial facility support and the support of manpower such as a new mechanical engineer at Temple University and the support of undergraduate students. In addition, a generous gift to the College of Science and Technology at Temple University allowed the purchase of various laboratory items.

List of eRD3 Publications

1. M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.08693].
2. Zhang et al., Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.07913].
3. M. Posik and B. Surrow, Nucl. Instrum. Meth. A 802, (2015) 10.
4. M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2016) [arXiv:1612.03776].

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